# $\gamma\gamma \to \mu\tau b\bar{b}$ in Susy Higgs mediated lepton flavor violation (*)

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**Summary.** — The process $\gamma\gamma \to \mu\tau b\bar{b}$ is studied in the minimal supersymmetric standard model within a large $\tan\beta$ scenario imposing on the parameter space present direct and indirect constraints from $B$ physics and rare LFV $\tau$-decays. At a photon collider based on an $e^+e^-$ linear collider with $\sqrt{s} = 800$ GeV with the parameters of the TESLA proposal (expected integrated $\gamma\gamma$-luminosity $L_{\gamma\gamma} = 200 \div 500$ fb$^{-1}$) the LFV signal can be probed for masses of the heavy neutral Higgs bosons $A, H$ from 300 GeV up to the kinematical limit $\simeq 600$ GeV for 30$\leq \tan\beta \leq$60.

The minimal super symmetric standard model (MSSM) (like the standard model) does not provide any explanation for the neutrino masses and mixing. In order to accomplish this task, the seesaw mechanism is usually implemented in the MSSM adding right handed neutrinos ($\nu$-MSSM). Compared to the MSSM, the main novelty in the $\nu$-MSSM is the presence of lepton flavor violation (LFV). LFV effects arise both in the gauge interactions [1] (through lepton-slepton-gaugino couplings) and in the Yukawa interactions [2]. In particular, LFV Yukawa interactions are greatly enhanced at large $\tan\beta$, and give the possibility of detecting LFV decays of the Higgs bosons at LHC [3, 4] and ILC in the $e^+e^-$ mode [5]. In Refs. [6] loop level lepton flavor violating processes such as $e^+e^- \to e^+\ell^-$ ($\ell = \mu\tau$), and $\gamma\gamma \to \ell_i\ell_j$ ($\ell_i \neq \ell_j$), which are potentially striking signatures of LFV, were studied in detail. Here we discuss a new mechanism of lepton flavor violation at the photon collider [7, 8] via the Higgs mediated $(H, A)$ process: $\gamma\gamma \to \mu\tau b\bar{b}$ in a scenario of large $\tan\beta$ where all the super-partner masses are $\mathcal{O}$(TeV) and the heavy Higgs bosons $(A, H)$ have instead masses below the TeV and develop sizable loop induced LFV couplings to the SM leptons.

In photon-photon collisions the main production mechanisms for the Higgs bosons are $\gamma\gamma$ fusion and $\tau\tau$ fusion [9]. In the first case, the Higgs is produced as an s-channel resonance through a loop involving the exchange of massive charged particles. In the $\tau\tau$ fusion process $\gamma\gamma \to \tau\tau b\bar{b}$, the Higgs is produced in the s-channel with a $\tau\tau$ pair and

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can be detected with its decay mode $b\bar{b}$. We have shown in Ref. [10] that the main LFV process is the $\mu\tau$ fusion to the Higgs, see diagram (a) in Fig. 1, top-left panel, which dominate the $\gamma\gamma$ fusion, with large cross section over large portion of the parameter space. The signal from the $\mu\tau$ fusion $\gamma\gamma \to \mu\tau b\bar{b}$ consists of a $\mu\tau$ pair plus $b\bar{b}$ jets from the Higgs decay, allowing the possibility to detect and reconstruct the Higgs through its main decay channel and to measure, at the same time, the size of LFV couplings. In the following we report the main results while detailed analysis of the signal and background can be found in Ref. [10].

In the mass-eigenstates basis for both leptons and Higgs bosons, the effective flavor-violating Yukawa interactions are described by the lagrangian:

$$(1) \qquad -\mathcal{L} \simeq (2G_F^2)^{\frac{1}{4}} \frac{m_{l_i}}{c_\beta^2} \left( \Delta_L^{ij} \bar{l}_R^i l_L^j + \Delta_R^{ij} \bar{l}_L^i l_R^j \right) \times (c_{\beta-\alpha} h - s_{\beta-\alpha} H - iA) + h.c.$$

where $\alpha$ is the mixing angle between the CP-even Higgs bosons $h$ and $H$, $A$ is the physical CP-odd boson, and we adopt the notation $(c_\theta, s_\theta, t_\theta) = (\cos\theta, \sin\theta, \tan\theta)$. In Eq. (1) $i, j$ are flavor indices that in the following are understood to be different ($i \neq j$).

The couplings $\Delta^{ij}$ in Eq. (1) are induced at one loop level by the exchange of gauginos and sleptons, provided a source of slepton mixing is present. In this work the analysis at Higgs LFV effects will be model independent and we use the expressions of $\Delta_{L,R}^{ij}$ obtained in the mass insertion approximation. The LFV mass insertions $\delta_{LL}^{ij}$ and $\delta_{RR}^{ij}$ are defined as: $\delta_{LL}^{ij} = (m_L^2)^{ij}/m_L^2$, $\delta_{RR}^{ij} = (m_R^2)^{ij}/m_R^2$, where $(m_L^2)^{ij}$ are the off-diagonal flavor changing entries of the slepton mass matrix.

The Higgs boson decay widths relevant for the following analysis at a photon collider are obtained by means of the lagrangian of Eq. (1) using the approximation $1/c_\beta^2 \simeq \tan^2\beta$ (only valid in the large $\tan\beta$ regime) and in the limit of massless fermions. Introducing $\Delta^2 = |\Delta_L^{32}|^2 + |\Delta_R^{32}|^2$ we find $\Gamma(A \to \tau^+\mu^-) + \Gamma(A \to \tau^-\mu^+) = t_\beta^2 \Delta^2 \Gamma(A \to \tau^+\tau^-)$. For the heavy Higgs boson $H$, the right hand side of the previous equation should be multiplied by a factor $(s_{\beta-\alpha}/c_\alpha)^2$. The light Higgs field $h$ has negligible lepton flavor violating decays since its coupling $\cos(\beta - \alpha) \to 0$ in the decoupling regime.

In Ref. [10] we have shown that a relieable estimate of the cross section, including cuts for background suppression, is given by considering only the diagram (a) of Fig. 1 (top-left panel) with the method of the equivalent particle approximation (EPA). The cross section for monochromatic photons is given by the convolution of the photon splitting functions to a pair of leptons [9], with the cross section in the center of mass frame of the sub-process $\mu\tau \to b\bar{b}$ in the small width approximation (SWA):

$$(2) \qquad \sigma(\gamma\gamma \to \mu\tau b\bar{b}) = \frac{4\pi^2}{s_{\gamma\gamma}} \frac{\Gamma(A \to \tau\mu)\mathcal{B}(A \to b\bar{b})}{M_A} 2 \int_{-\ln 1/t}^{+\ln 1/t} d\eta \, P_{\gamma/\mu}(te^\eta) \, P_{\gamma/\tau}\left(te^{-\eta}\right)$$

where $s_{\gamma\gamma}$ is the photons center of mass energy squared, the factor two is the multiplicity factor which accounts for the exchange of the initial photons, $\eta = \ln\sqrt{x_\mu/x_\tau}$, $t = M_A/2E_\gamma$, $x_\mu$, $x_\tau$ being the colliding photon's energy fraction carried by the $\mu$ and $\tau$ .

In order to provide a detailed study of the possibilities of a photon collider with respect to the LFV violating signal $\gamma\gamma \to \mu\tau b\bar{b}$ we performed a scan over the following parameter space: $1\,\mathrm{TeV} \leq (\mu, m_{\tilde{q}}, A_u, A_d, m_L, m_R) \leq 5\,\mathrm{TeV}, 500\,\mathrm{GeV} \leq (M_1, M_2, M_3) \leq 5\,\mathrm{TeV}, 150\,\mathrm{GeV} \leq M_A \leq 1\,\mathrm{TeV}, 30 \leq \tan\beta \leq 60, 10^{-3} \leq (\delta_{LL}^{32}, \delta_{RR}^{32}) \leq 0.5.$

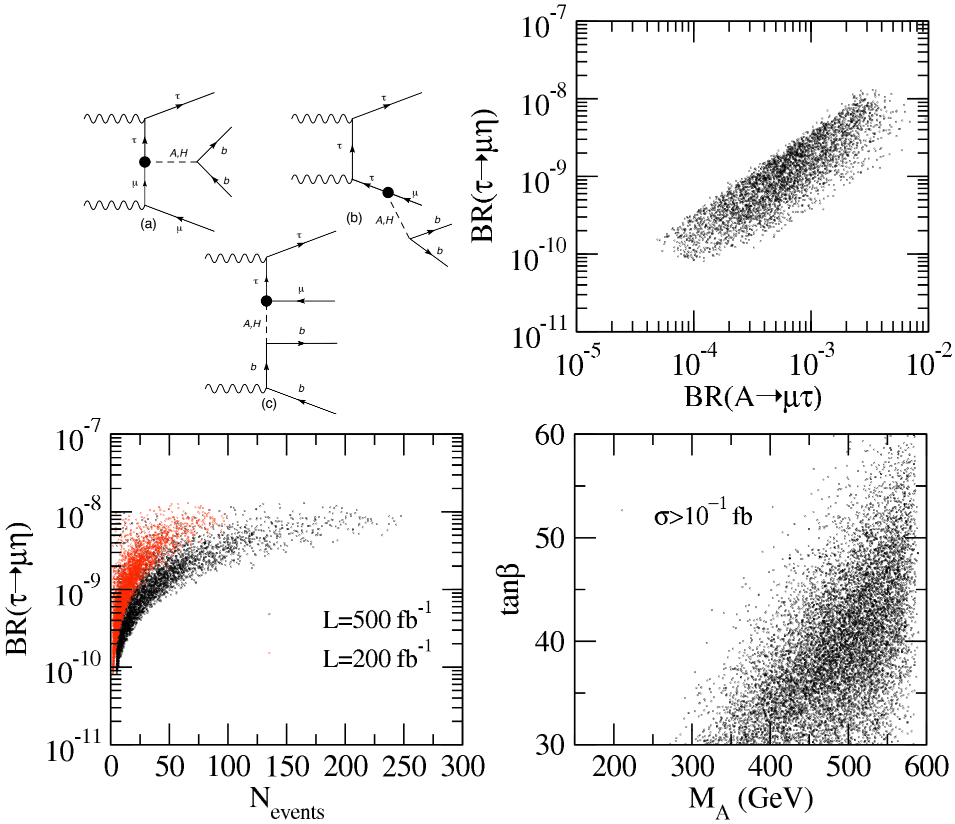


Fig. 1. – (Top left panel) Diagrams for the process $\gamma\gamma \to \mu\tau b\bar{b}$: the topology (a) is the one we call $\mu\tau$ fusion. The black blob represents the loop induced LFV coupling treated as an effective vertex. (Top right panel) Correlation between $\mathcal{B}(\tau \to \mu\eta)$ and $A \to \mu\tau$. (Bottom left panel) Correlation between $\mathcal{B}(\tau \to \mu\eta)$ and the number of expected events for two values of the integrated luminosity. (Bottom right panel) Distribution of the signal cross section in the $(M_A, \tan\beta)$ plane. The parameter space and the imposed constraints are discussed in the text.

We impose the following constraints on the parameter space: lower bound on the light Higgs mass $m_h > 114.4$ GeV; upper bound on the anomaly of the muon magnetic moment $(g-2)_\mu < 5 \times 10^{-9}$ ; bounds on electro-weak precision observables such as $\Delta\rho < 1.5 \times 10^{-3}$; direct search constraints on the lightest chargino and sfermion masses and constrains on squarks and gluino masses from LEP and Tevatron are automatically satisfied as they lie in the TeV range in our scenario. Some $B$-physics processes, namely $B_s \to \mu^+\mu^-$, $B \to X_s\gamma$ and $B_u \to \tau\nu$, are particularly sensitive to $\tan\beta$ [11]. We require that the parameter space satisfies $\mathcal{B}(B_s \to \mu^+\mu^-) < 6.5 \times 10^{-8}$ [12]; $R_{\tau\nu}$, the ratio between the SUSY and SM branching ratios for $B_u \to \tau\nu$, is required in the range $0.70 < R_{\tau\nu} < 1.44$; $R_{X_s\gamma}$, the ratio between the SUSY and SM branching ratios for $B \to X_s\gamma$, is required to lie in the range $1.01 < R_{X_s\gamma} < 1.25$ [13]. We impose the current upper bounds on LFV $\tau$ decays to be respected: $\mathcal{B}(\tau^- \to \mu^-\eta) < 6.8 \times 10^{-8}$ and $\mathcal{B}(\tau^- \to \mu^-\gamma) < 5.6 \times 10^{-8}$ [12]. In the case where Higgs-mediated LFV effects are important, $\tau \to \mu\eta$ is generally the dominant process [11].

In the top-right panel we show the correlation between $\mathcal{B}(\tau \to \mu\eta)$ and $\mathcal{B}(A \to \mu\tau)$. The latter gets values in the interval $(5 \times 10^{-4}) \lesssim \mathcal{B}(A \to \mu\tau) \lesssim (8 \times 10^{-3})$. Even if the upper limit on $\mathcal{B}(\tau \to \mu\eta)$ is lowered by an order of magnitude from its actual value ($\approx 10^{-8}$) we see that $\mathcal{B}(A \to \mu\tau)$ can still reach values up to $\mathcal{O}(10^{-3})$ which are particularly interesting for the LHC, where the cross section for heavy neutral gauge bosons production in $b\bar{b}$ fusion is sizable [4].

In the bottom-left panel of Fig. 1 we show the correlation between $\mathcal{B}(\tau \to \mu\eta)$ and the number of $\mu\tau b\bar{b}$ events corresponding to the cross sections for monochromatic photon collisions at $\sqrt{s_{\gamma\gamma}} = 600$ GeV for two values of the integrated luminosity, $\mathcal{L} = 200 - 500$ fb$^{-1}$/yr. It can be seen that for the high luminosity option we can expect up to 250 events per year, and up to 100 events per year for the low luminosity option. The above conclusions are valid for the present upper limits on the branching ratios.

In the bottom-right panel we show the region of the parameter space in the $(M_A, \tan\beta)$ plane which is characterized by a signal cross-section $\sigma \geq 10^{-1}$ fb. The signal cross-section becomes larger at low $M_A$ masses, but in the considered region of large $\tan\beta$ values such low masses are excluded by the imposed constraints. In particular, the LFV signal for $M_A$ masses below 300 GeV are excluded for all values of $\tan\beta$ in the interval, $30 < \tan\beta < 60$. We have checked that requiring a signal cross section $10^{-2}\text{fb} \leq \sigma \leq 10^{-1}$ fb the same region in the $(M_A, \tan\beta)$ plane is covered.

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